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DECOMPOSITION AND PLANT NUTRIENT RELEASE FROM LITTER IN TWO FOREST ECOSYSTEMS

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The dissertation is based on the following five papers:

I. Staaf, H. 1979. Release of plant nutrients from decomposing leaf litter in a South Swedish beech forest.

II. Staaf, H. 1979. Influence of chemical composition, addition of raspberry leaves, and nitrogen supply on decomposition rate and dynamic of nitrogen and phosphorus in beech leaf litter.

III. Berg, B. & Staaf, H. 1979. Decomposition rate and chemical changes of Scots pine needle litter. I. The influence of stand age. - Accepted for publication in Ecological Bulletins (Stockholm).

IV. Berg, B. & Staaf, H. 1979. Decomposition rate and chemical changes of Scots pine needle litter. II. The influence of chemical composition. - Accepted for publication in Ecological Bulletins (Stockholm).

V. Bosatta, E., Bringmark, L. & Staaf, H. 1979. Nitrogen transformations in a Scots pine forest mor - model analysis of mineralization, uptake by roots, and leaching. - Accepted for publication in Ecological Bulletins (Stockholm).

References to these papers are made by using the relevant roman numerals.

INTRODUCTION

Results from a vast number of studies on nutrient cycling and forest fertilization have stressed the importance of mineral nutrients and nitrogen in regulating forest productivity. Especially nitrogen seems to be a limiting factor for primary productivity of most coniferous and deciduous forests of both temperate and boreal zones (Duvigneaud & Denaeyer-De Smet 1970, Tamm 1975).

Plant nutrients are either incorporated into woody tissue as structural components, or continuously reused in metabolic functions of growing plant organs. In both cases they are transferred , sooner or later, to soil by litter shedding, but a certain part of the mobile pool is retained in plant biomass by translocation processes. A rapid and efficient recycling of plant nutrients in the plant-soil system or an efficient redistribution within plants appear to be two ways of sustaining a high and persistent productivity. Both mechanisms are important in forests (Curlin 1970), but the recycling via the decomposer community determines the level of nutrient accumulation and turn-over rate in soil organic matter in a long-term perspective. Normally, biological cycles in forests are very tight, but human activities may cause extensive losses from the ecosystem (Witkamp & Ausmus 1976). A thorough knowledge of the functions regulating nutrient cycling is thus a desirable basis for forest management programs.

Bioelement supply from soil detritus to plant roots is difficult to measure explicitly, since several transfers, both biotic and abiotic, are involved in it. Weight loss of litter, on the other hand, can be conveniently measured by means of litter bag technique. In the present approach, combination of such measurements with chemical analyses was used in studying the release pattern of major plant nutrients from litter in two forest ecosystems; a Scots pine (Pinus silvestris L.) forest in central Sweden and a beech (Fagus silvatica L.) forest in southern Sweden. The aim was to answer the following questions:

- Can plant nutrient release leaf litter in the above-mentioned forests be characterized by measuring weight loss of litter?
- What internal chemical factors determine weight loss and plant nutrient release from leaf litter?
- Can existing hypotheses on nitrogen mineralization and transports in soil be combined to describe the annual and seasonal uptake in plants under field conditions?

LITTER DECOMPOSITION

Weight loss of different litter types

Needle litter of Scots pine and beech leaf litter both exhibited a relatively slow decomposition rate during field conditions (I, III and IV). Annual weight loss was about 25-30% of initial weight, of which one-third could be attributed to winter periods.

This similarity is remarkable, since the beech site, which is situated 600 km to the south of the investigated Scots pine site and at a lower altitude, has a more humid climate, about three months longer vegetation period, about 3°C higher annual mean temperature and a more finely structured and fertile soil than the pine site. Furthermore, the concentrations of the elements N, P, K, S, Ca and Mg are two to ten times higher in the beech litter than in the needle litter. This together with the fact that wild raspberry leaves (Rubus idaeus L.) decomposed with a four-fold higher rate than beech leaf litter on a beech forest soil (II), indicates that the organic chemical composition or anatomical - morphological properties determine the general level of litter turn-over rate. The limits of variation for a certain litter type is then set by the local environment conditions.

The high lignin level of beech leaf litter (II), initially near 40% of total weight, is a plausible explanation of its relatively low decomposition rate. In raspberry leaves the level was 17% at leaf fall and in pine needle litter of unfertilized trees just below 30%.

Influence of chemical composition

In Scots pine needle litter from trees given different doses of nitrogen fertilizer a positive influence of an increased initial plant nutrient level could be noted during the first year of decomposition (IV). The influence of nitrogen, phosphorus and sulphur concentrations could not be separated from each other, while potassium, calcium and magnesium did not seem to regulate decomposition rate (IV).

The plant nutrient influence was exhibited during a period when mainly water- and acetone-soluble fractions were decomposed. Lignin did not start to degrade until it had reached a concentration of about 30%, and at a total weight loss of 30% the positive influence of plant nutrients was overrun by a retarding action of the, relatively seen, enlarged lignin component (IV). This was accomplished both by its own slow decomposition rate and a retarded cellulose and hemicellulose decomposition.

The naturally occurring inter-site variation in plant nutrient concentration of Scots pine litter is probably not greater than in the present material. Such a variation is then likely to have an insignificant influence on decomposition rate in a long-term perspective of several years. Instead, organic compounds, and especially lignin, have a major regulating power on decomposition rate of lignin-rich litters (IV), in addition to environmental conditions. How this is expressed in the field is difficult to evaluate, since the variation in organic chemical composition among different sites is very incompletely known at present.

Beech leaf litter from three contrasting forest types in southern Sweden had somewhat different plant nutrient concentrations, but only slightly different lignin concentrations (II). Weight loss rates were also very similar at identical environmental conditions, and a tendency for a similar development over time as for needle litter could be noted. The results indicate that the plant nutrient level, in this case probably nitrogen, regulated the initial weight loss rate, while availability of carbon or energy became limiting to decomposers at later stages.

Beech leaf litter quality appears only to have a weak influence on the inter-site variation in litter turn-over rate. Such differences, which are considerable among different beech forest types in southern Sweden (Nihlgård & Lindgren 1977), should mainly be looked for among local climatic or soil biological variables.

PLANT NUTRIENT RELEASE

Different release patterns

Some general types of plant nutrient losses from litter over time, in common for needle litter (IV) and beech leaves (I), could be distinguished. Up to about 50% weight loss the element concentrations either increased, decreased or remained constant giving the following main patterns:

- Potassium, and for beech leaves also sodium, was initially quickly leached from litter, whereafter the remaining amounts became almost constant. Magnesium had a similar trend, but the initial losses were less pronounced and spread out over a longer period.
- Calcium release was characterized by a relatively close coupling to litter weight loss for the whole period.
- Nitrogen, phosphorus and sulphur were all accumulated during the first half of the mentioned decomposition period, and then the carbon-element ratio became approximately constant. This development was most clearly seen for beech leaf litter.
- Iron, zinc and copper were only investigated for beech leaf litter. The development was similar to that of the foregoing group, but these elements were still more strongly accumulated in litter; the absolute amounts increased up to 200-400% of the initial content per leaf. During the second year of decomposition this accumulation levelled out.

Generally speaking it can be said that for the two investigated litter types weight loss measurements give an accurate image of plant nutrient release only in the case of calcium. The net changes of all other nutrients over time are highly variable or are lost at considerably different **rates than total weight loss** ; this applying at least to periods of one year's length or shorter. For longer periods, however, it appears that the net release can be approximated by multiplying total weight loss by the initial litter concentration of the various elements.

Regulating factors

The release pattern of a certain plant nutrient element from litter is mainly determined by (a) how the element is chemically bound in litter (b)the need for the element in microbial decomposer tissue build-up and (c)the element concentration.

Potassium and sodium are not structural parts of the organic matter and are not limiting for decomposer activity. To a great extent they are passively lost by mechanical leaching. Factors that influence water entrance into the litter structure should thus regulate the initial losses. A certain part of the total amount is more firmly enclosed in the litter structure and is successively released during decomposition. During the course of decomposition the adsorption capacity of litter increases, which reduces losses, especially of potassium.

Magnesium is similar to K and Na in the above-mentioned respects and its release is also directly influenced by abiotic factors, e.g. enhanced by the climatic conditions on a clear-cut area compared to those in a closed pine forest (III). A certain part is bound to organic chelates, which is likely to explain its reduced initial rate loss compared to potassium (I, III, IV).

Calcium release is determined by the same mechanisms that regulate litter weight loss. A large part of the element is enclosed or bound to cell wall structures and is transferred to the soil water phase with the successive microbial tissue breakdown . Its adsorption tendency is also very strong.

Nitrogen, phosphorus and sulphur are all needed in macro-quantities by decomposer organisms and are preferably covalently bound in litter. The release mechanism is mainly enzymatic mineralization, but the elements are efficiently retained in decomposer biomass as long as the concentrations in the substrate are suboptimal for decomposer growth. This explains the initial accumulation in litter during the plant nutrient controlled decomposition phase (I, IV) when mainly easily assimilated compounds are decomposed. In the subsequent lignin-controlled phase the elements are in excess and their release runs approximately parallel to total weight loss.

If initial concentrations exceed a certain level a net release is initiated already at the onset of decomposition. For needle litter 6, 0.25 and 0.35 mg g^{-1} appeared to correspond to this point for N, P, and S respectively (IV). Total concentrations are, however, not always an appropriate index of availability, which makes it difficult to interpret such figures in terms of optimal substrate composition for decomposer utilization. Even for the same litter type, in this case beech leaf litter, the threshold points for nitrogen accumulation during decomposition obviously did not correspond to a specific C/N ratio (II).

Importance in forest nutrient cycling

Plant litter is an important carrier substance in the plant nutrient recycling of forests. Of the major plant nutrient elements decomposition and/or mineralization are considered the main transfer mechanism to the soil water phase and thereby to plant roots for nitrogen, phosphorus and calcium in the investigated beech forest (I). Potassium and sulphur are more closely coupled to the water transports, and magnesium has an intermediate position in this respect. Similar conclusions can be drawn for the Scots pine forest (Bringmark 1977).

In many forests there is rapidly decomposing field vegetation litter, which may give considerable and sudden flushes of released inorganic plant nutrients to soil. Nitrogen and phosphorus can be transferred from this kind of litter, in this case raspberry leaves,to beech leaf litter (II). This might be an important mechanism in levelling out the supply to roots and reduce losses by leaching. During initial periods of decomposition litter may act as a sink for one or several of the elements N, P and S by transfer and immobilization by microbes (I, IV). The retaining tendency can be expected to be especially pronounced in litter types that are poor in these elements, since the initial concentration in litter was found to be important in regulating the process (IV).

Modelling

An attempt was made to test the theoretical basis for describing nitrogen transfers in soil. It was made by constructing a model for these processes of the Scots pine forest mor (V). Nitrogen mineralization, formulated from a simple assumption of carbon and nitrogen as limiting factors for microbial decomposition, was integrated with formulations of inorganic nitrogen transports and uptake in roots. The description of the seasonal fluctuations was complicated by the difficulty in predicting variations of the inorganic nitrogen soil pool, even if its size was comparatively small and the coupling between mineralization and uptake was close. An incomplete knowledge of microbial immobilization, in combination with a rough substrate definition, was considered an important factor for this inaccuracy of the model. Furthermore, in modelling long-term trends there is need for a formal muneralization hypothesis based on chemical substrate quality and climatical variables only, since decomposer biomass is difficult to describe during winter periods, and there are at present no means of determining their absolute growth rate on a changing substrate.

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